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Search for Supersymmetry at the Tevatron

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(for the DØ and CDF collaborations)

Abstract. We discuss is the search for supersymmetry at the Fermilab Tevatron by the DØ and CDF collaborations in $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV. The searches are performed in the jets plus $\not\!\!E_T$, leptons plus $\not\!\!E_T$, and photons plus $\not\!\!E_T$ channels. In these channels there is no excess of events over the expected backgrounds.

INTRODUCTION

The Standard Model (SM) has been very successful in describing our current understanding of high energy physics. However, the SM is not without its defects, and there are strong reasons to believe that new physics, and particles, exist beyond what have been observed. One extension of the SM is called Supersymmetry [1] (SUSY). Supersymmetry states that every SM particle has a supersymmetric partner with the same quantum numbers but differing by 1/2 unit of spin. This paper is a description of *some* of the searches for SUSY at the DØ and CDF collaborations.

THE DETECTORS

The Tevatron is currently the highest energy accelerator in the world, colliding protons and antiprotons with a center of mass energy of 1.8 TeV. The high energy allows a unique opportunity to search for new particles with large masses. The two collider detectors at Fermilab are DØ and CDF. Each is a large multipurpose detector used to measure charged leptons, photons, and jets. Moving radially from the beamline the DØ detector consists of a non-magnetic central tracking system, a compact uranium-liquid argon calorimeter, and a muon spectrometer. The CDF detector has a central tracking system, immersed in a 1.4T magnetic field, which is surrounded by a calorimeter and a muon system.

SQUARK AND GLUINO SEARCHES

At the Tevatron squarks ($\tilde{q}$) and gluinos ($\tilde{g}$) would be produced through the strong interactions since they carry color. If R parity is conserved SUSY particles are produced in pairs. When squarks and gluinos decay they may cascade decay into quarks, gluons, charginos ($\tilde{\chi}^{\pm}$), and neutralinos ($\tilde{\chi}^{0}$). The charginos and neutralinos may decay into leptons plus the lightest stable supersymmetric particle (LSP). The LSP is typically taken to be $\tilde{\chi}_1^0$ and is not observed in the detector. Therefore SUSY signatures arise from the jets from the quarks and gluons, the leptons from the charginos and neutralinos, and $\not\!\!E_T$ from the LSPs.

Dileptons and $\not\!\!E_T$

The DØ collaboration searches for squarks and gluinos using the dielectron plus $\not\!\!E_T$ channel in 93 pb^{-1} of data [2]. The search requires two electrons with $E_T > 15$ GeV and two jets with $E_T > 20$ GeV. The $\not\!\!E_T$ is required to be greater than 25 GeV, or 40 GeV if the dielectron mass is within 12 GeV of the Z mass. After these cuts only two events are left with an expected background of 3.0 ± 1.3. The backgrounds are mainly due to $t\bar{t}$ production and $Z \to \tau\bar{\tau}$. Since there is no excess of events over background the result is presented, in the minimal supergravity (SUGRA) framework, as a limit in the m_0 and $m_{1/2}$ plane with $A_0 = 0$, $\tan\beta = 2$, and $\mu < 0$ (see Fig. 1). For equal $\tilde{q}$ and $\tilde{g}$ masses a limit of 267 GeV is obtained.

The CDF collaboration searches for gluinos using same sign dileptons [3]. Since the gluino is a Majorana particle the two gluinos decay into charginos with the same sign 50% of the time. In 90 pb^{-1} of data the analysis requires an electron or muon with $E_T > 11$ GeV, a second with $E_T > 5$ GeV, two jets with $E_T > 15$ GeV, and $\not\!\!E_T > 25$ GeV. The requirement of same-sign leptons leaves two events. The background from $t\bar{t}$ and Drell-Yan events is estimated to be $1.28 \pm 0.61(stat) \pm 0.35(syst)$. The limit is presented in the $M_{\tilde{q}}$–$M_{\tilde{g}}$ plane for the grand unified theory (GUT) inspired minimal supersymmetric standard model (MSSM) parameters (see Fig. 1).

Jets and $\not\!\!E_T$

A search in the jets plus $\not\!\!E_T$ channel complements the dilepton modes. This is because the decay of the SUSY particles into leptons can be very sensitive to the choice of model parameters, *e.g.* $\tan\beta$. Therefore, a search which does not depend on leptons explores a region of parameter space not accessible to the lepton modes. Each experiment has searched for squarks and gluinos in the jets and $\not\!\!E_T$ channel.

The most recent DØ search [4] in the jets plus $\not\!\!E_T$ channel is based on 72 pb^{-1} of data. The analysis requires 3 jets with $E_T >$ 25 GeV, with the leading jet having $E_T >$ 115 GeV and $|\eta|<$1.1. The leading jet is used to confirm the primary vertex because a mismeasured vertex will lead to significant spurious $\not\!\!E_T$. Also, the event $\not\!\!E_T$ is required to be uncorrelated with the jets, and any isolated electrons and muons are vetoed. The backgrounds are due to vector boson production in association with jets and $t\bar{t}$ production. The vector boson backgrounds are simulated with VECBOS [5] and the $t\bar{t}$ background with HERWIG [6]. The multijet background is determined from a data set taken without $\not\!\!E_T$ in the trigger. The $\not\!\!E_T$ distribution is fit and extrapolated into the region of interest for this analysis. The cuts on $\not\!\!E_T$ and H_T, where H_T is the scalar sum of the non-leading jets, are optimized at each point in parameter space. The number of events observed is 15 with an expected background of 9.3 $\pm$ 3.4. Since there is no significant excess over background this result is interpreted as an exclusion contour in the m_0 and $m_{1/2}$ plane for $\tan\beta = 2$, $A_0 = 0$, and $\mu < 0$ (see Fig. 1).

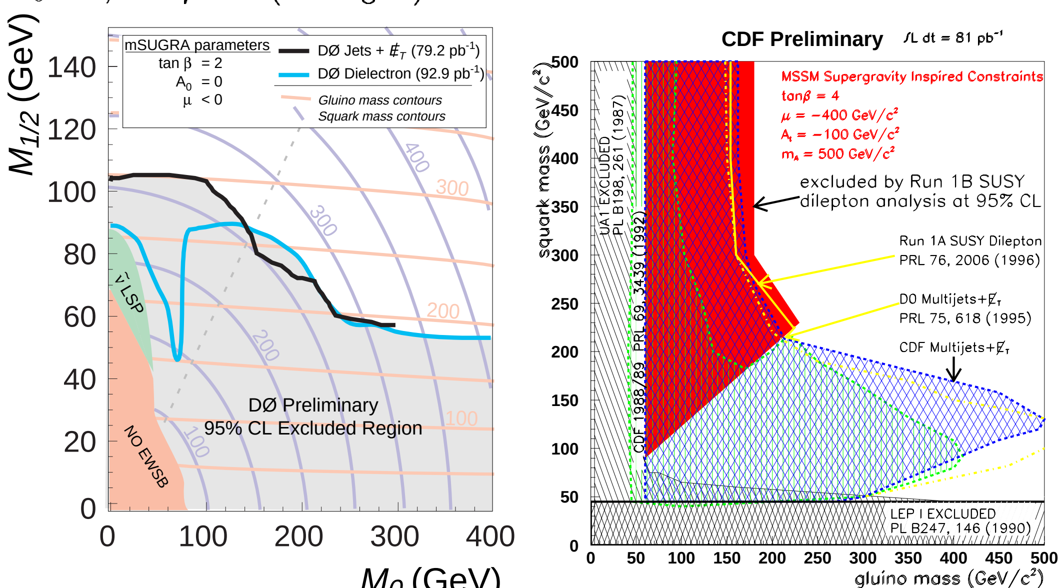

FIGURE 1. The DØ dielectron plus $\not\!\!E_T$ and jets plus $\not\!\!E_T$ limits in the m_0 and $m_{1/2}$ plane (left). The CDF dilepton plus $\not\!\!E_T$ and jets plus $\not\!\!E_T$ limit in the $M_{\tilde{g}}$ and $M_{\tilde{q}}$ plane (right).

The CDF jets plus $\not\!\!E_T$ search is based on 19 pb^{-1} of data where 3 or 4 jets are required with $E_T>$15 GeV and $|\eta|<$2.4 [7]. The $\not\!\!E_T$ is required to be greater than 60 GeV and $S >$ 2.2 GeV$^{1/2}$, where $S = \not\!\!E_T/\sqrt{\sum_i E_T^i}$. The vector boson background is taken from the VECBOS generator normalized to the Wjj data. The $t\bar{t}$ backgrounds are generated with the ISAJET [8] generator and normalized to the CDF measured cross section. In the 3(4) jets channel there are 24(6) events observed with an expected background of 33.5±19.4(8.0±5.7). This limit is expressed in terms of the $\tilde{q}$ and $\tilde{g}$ masses in Fig. 1.

CHARGINO AND NEUTRALINO SEARCHES

Charginos and neutralinos may be produced directly at the Tevatron through their electroweak couplings to squarks and vector bosons. Though, the decay of these particles is highly sensitive to the choice of model parameters, the chargino and neutralino may be light and therefore accessible to Tevatron energies.

Trileptons and $\not\!\!E_T$

The search for events with trileptons and $\not\!\!E_T$ is considered to be one of the golden channels for discovering new phenomena since the SM backgrounds are very small. Both DØ and CDF have searched for events with three leptons (electrons or muons) and $\not\!\!E_T$.

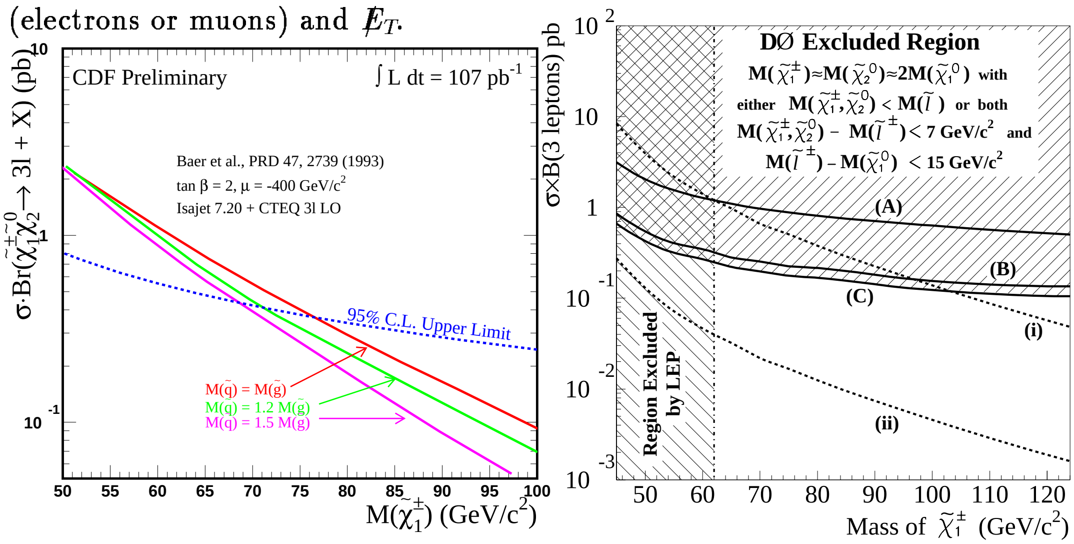

FIGURE 2. The CDF (left) and DØ (right) trilepton limits as a function of the mass.

The CDF search [3] is based on 107 pb^{-1} of data and requires three electrons, muons, or a combination of both, with the leading lepton E_T>11 GeV and the trailing two with E_T>5(4) GeV for electrons(muons). Invariant mass cuts are applied on same flavor leptons to remove the J/ψ, Υ, and Z resonances. Also, the leptons are required to be isolated. After the cuts 6 events remain. Adding a $\not\!\!E_T$>15 GeV cut removes all of these. The expected background of 1.5 events is dominated by Drell-Yan events with a fake lepton. The limits are expressed in terms of the branching ratio into three leptons as a function of the chargino mass and are shown in Fig. 2.

The DØ search [9] is similar to the CDF search in that the analysis requires three leptons with E_T>5 GeV, though the leading two leptons may be higher due to trigger requirements. The leptons are required to be isolated and mass cuts are used to remove the resonances. After the $\not\!\!E_T$>15 GeV cut is applied to the 95 pb^{-1} of data no events remain. The main background is Drell-Yan plus a fake lepton, and total of 1.3 events are expected from all backgrounds. The limit as a function of the chargino mass is shown in Fig. 2.

PHOTONS AND $\not\!\!E_T$

Even though there has been no excess of signal from SUSY in the data there are events that appear inconsistent with SM description. One event in particular, observed at CDF, contains two high E_T electrons, two high E_T photons, and large $\not\!\!E_T$ [10]. The observation of this event has led to a number of papers with possible SUSY interpretations [11]. One explanation is from gauge-mediated SUSY breaking models where the neutralino decays into a photon (γ) and gravitino ($\tilde{G}$); the gravitino is the LSP. In this model the event is selectron production where $\tilde{e} \to e\tilde{\chi}_1^0 \to e\gamma\tilde{G}$. A second model is a region of MSSM space where $\tilde{\chi}_2^0$ decays to $\gamma\tilde{\chi}_1^0$. Again the $ee\gamma\gamma\not\!\!E_T$ event is interpreted as the production of selectrons with the decay ($\tilde{e} \to e\tilde{\chi}_2^0 \to e\gamma\tilde{\chi}_1^0$).

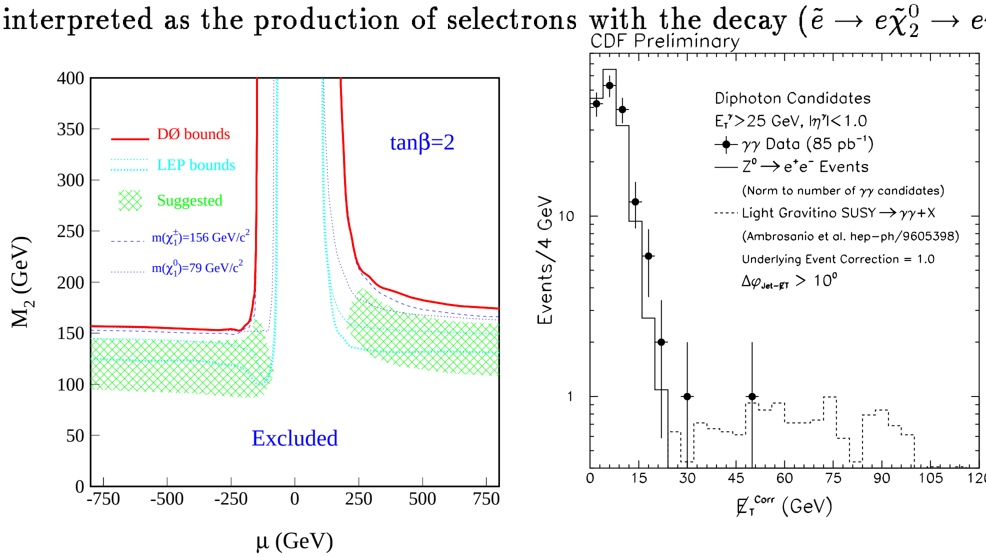

FIGURE 3. The DØ diphoton limit (left) as a function of M_2 and μ, and the $\not\!\!E_T$ distribution from the CDF analysis (right).

Each experiment has performed a SUSY search of inclusive diphoton events with $\not\!\!E_T$. The DØ search is based on 106 pb^{-1} of data and requires two photons with E_T>20 and 12 GeV and $\not\!\!E_T$>25 GeV [12]. With these cuts two events remain with an expected background of 2.3 ± 0.9. In the light gravitino LSP model with $M_2 \sim 2M_1$, and for a heavy $M_{\tilde{q}}$, the limits can be presented as a function of M_2, μ, and $\tan\beta$. The SPYTHIA [13] Monte Carlo is used to generate events as a function of these parameters with the limits shown in Fig. 3. The hatched area in Fig. 3 is the region proposed to explain the $ee\gamma\gamma\not\!\!E_T$ event and is clearly ruled out by this measurement.

The CDF search is based on 85 pb^{-1} of data and requires two photons with E_T>25 GeV and $\not{E}_T$>35 GeV [3]. The photons are required to have $|\eta|<1.0$, and the $\not{E}_T$ cannot be along a jet direction. The distribution of events, as a function of $\not{E}_T$, is shown in Fig. 3 and the determination of limits is underway.

CONCLUSIONS

At the Tevatron the search for SUSY so far has not observed any excess of events over the expected SM backgrounds, though interesting events do exist. The DØ and CDF collaborations continue to search for new SUSY decay channels in the existing data and with improved techniques gained from experience in previous studies. A future run of the Tevatron, to begin in 1999, anticipates a twenty fold increase in luminosity and an increase in the center-of-mass energy to 2 TeV. This will allow the DØ and CDF collaborations with upgraded detectors to stay at the forefront of the search for new phenomena into the next decade.

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